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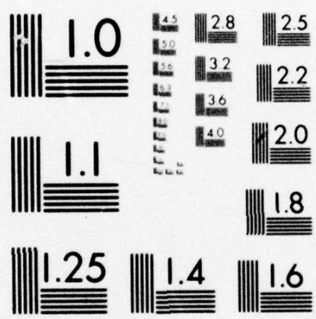
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

ORBIT PREDICTION ERRORS RESULTING FROM VERTICAL MISALIGNMENT OF A RADAR ANTENNA

A. FREED

Group 91

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ABSTRACT

Accidental misalignment of an antenna's vertical reference axis with respect to the local vertical introduces errors into the measurements of azimuth and elevation directly. If corresponding corrections are neglected, relatively small misalignments can prevent a radar from achieving high-accuracy orbit-determination. The use of electronic level-sensors for making such corrections in real-time is described. Some numerical examples are presented to illustrate the problem.

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ORBIT PREDICTION ERRORS RESULTING FROM

VERTICAL MISALIGNMENT OF A RADAR ANTENNA

I. INTRODUCTION

Among the continuing tasks for an operational radar site are the monitoring and maintenance of requisite calibration. The development of new techniques for attaining a specified degree of measurement accuracy poses a special challenge when existing radars are to be upgraded to meet new mission objectives.

As a factor of importance in overall pointing calibration, vertical misalignment may vary both in magnitude and direction quite markedly. This variation may even occur over short periods of time in some instances. Under these circumstances, efforts to develop good pointing-error models *empirically* may be frustrated. Such efforts usually seek to determine a number of different parameters by least squares minimization of differences between observations and computations. The problem is distinctly non-linear, and frequently the assumption is made that any vertical misalignment (tilt) which may be present is constant.

The validity of such an assumption needs to be determined in each instance. The use of direct measurement where economically feasible removes at once a source of error and a cause of possible confusion. It has the further advantage of reducing both the number of unknowns remaining and perhaps their associated uncertainties as well.

As a means of monitoring and correcting for time-varying misalignment of the vertical reference-axis with respect to the local vertical, electronic level-sensors play a role of demonstrated utility at the Millstone Hill radar.[1] Improved instruments are currently available at relatively low cost. The acquisition of level-sensors with real-time output to the computer could be greatly beneficial to present calibration efforts at various ADCOM radars. They might well prove essential if future calibration objectives are to be met.

The Millstone Hill tracking radar was originally designed in 1957 for UHF. In 1962, the radar was extensively modified and reconfigured for L-band.[2] The antenna is an 84-foot diameter parabolic dish with a Cassegrain subreflector approximately ten feet across. A specially designed twelve-horn feed system provides monopulse error signals for tracking.

The azimuth deck rotates with the antenna and supports a sizeable equipment shelter. Lead counterweights are held in a butterfly-wing configuration behind the main reflector to balance the antenna about the elevation axis. The total weight is roughly eighty tons.

The supporting pedestal is about ninety feet high. It consists of a steel cone of one half this height atop a cylindrical concrete base. The entire structure is exposed to the elements on an open hilltop and was designed to withstand 100 mph winds.

Figure 1 shows a view of the top portion of the antenna, and further details concerning its mechanical and electrical characteristics are given in Reference 3.

The Millstone Hill radar antenna was a prototype which continues to be of current interest. Millstone is a SPACETRACK contributing sensor whose present tracking activities are almost exclusively devoted to deep-space targets for ADCOM. A number of existing SPACETRACK radars and other cooperating sensors have antennas which are similar. However, the essential point to be discussed in the sequel does not depend entirely upon the type of antenna. Misalignment of the vertical reference-axis with respect to the local vertical may occur in the structure supporting a phased-array antenna just as well as with a pedestal supporting a steerable dish.

The problems to be discussed will be those encountered at Millstone. These would be expected to exist at least in part at other sites. The benefit of actual first-hand experience in dealing with such problems at Millstone should be directly applicable elsewhere.

II. PREVIOUS MILLSTONE RESULTS

It had long been recognized that the antenna pedestal at Millstone was not precisely vertical. Measurements at various times over the years showed misalignment (tilt) on the order of

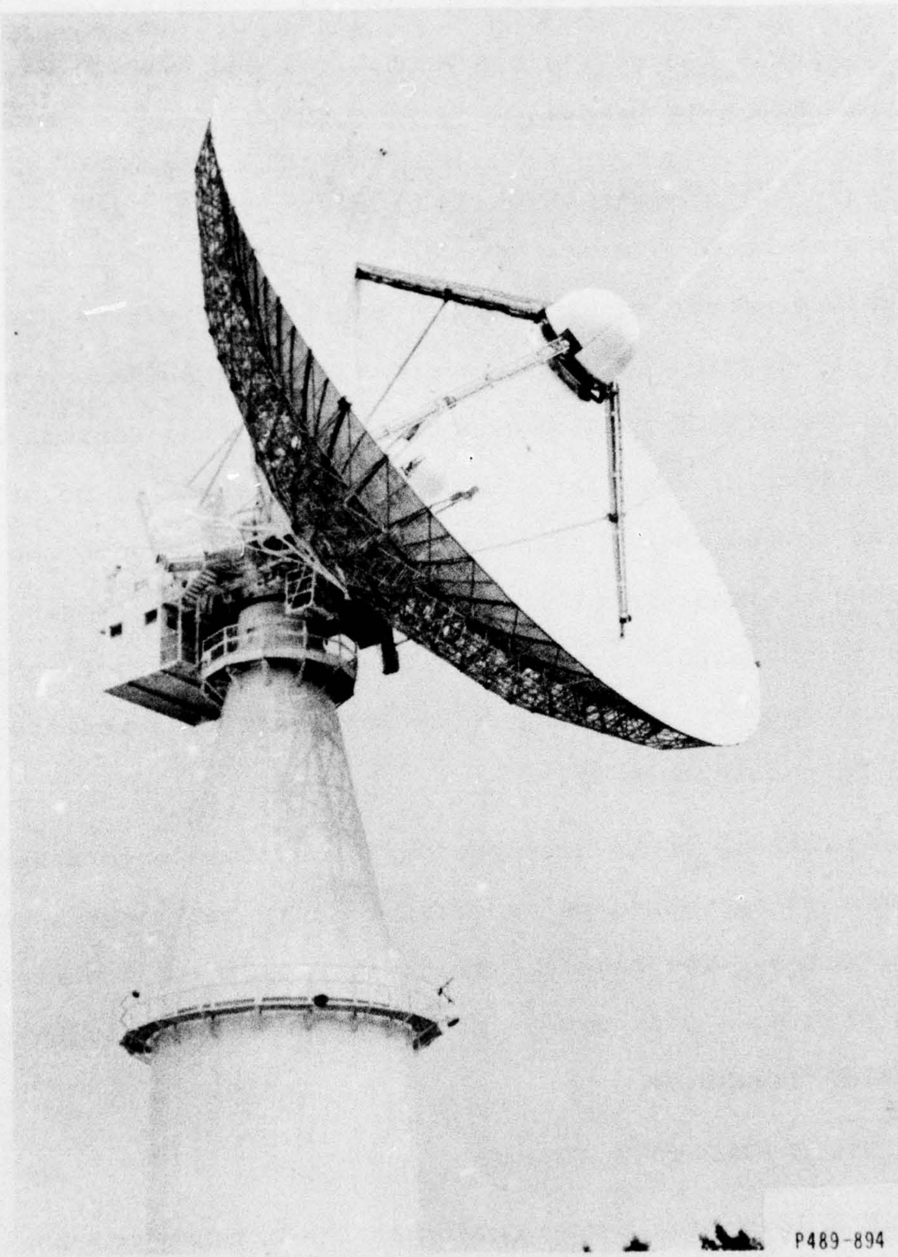

Fig. 1. Millstone Hill Radar Antenna.

15 - 25 mdeg. Because the support structure was so massive, it was generally assumed that this misalignment was relatively fixed. Estimates of tilt were computed (along with other antenna parameters) from observations of radio stars having very well known ephemerides. Typically, such observations were gathered at night. No effort was directed specifically toward measurement of possible short-term variations of tilt with time. It was 1971 before rigorous new calibration efforts led to more careful re-examination of the basic assumption concerning constant tilt.[1]

A series of simple tests using an electronic level-sensor quickly demonstrated that the vertical misalignment was indeed variable. The instrument was fastened to the azimuth deck, and the antenna was rotated a full 360 deg in azimuth a number of times over the course of a day. In the same way that the bubble in a carpenter's level would have shown varying offsets for varying orientations, the electronic level-sensor output varied sinusoidally with azimuth.

The amplitude of the sinusoid represents the maximum deviation from horizontal. It is thus related to the magnitude of the vertical misalignment. The azimuth at which this maximum occurs depends, of course, on the position of the level-sensor, but it is also directly correlated with the direction towards which the tower leans.

Both the magnitude of tilt and its direction changed slowly during the course of the day in apparent response to the changing direction of the sun (Fig. 2). Sharp changes at sunrise and at sunset were particularly noteworthy(Fig. 3). These unexpected effects were attributed to temperature gradients developed across the metallic upper half of the tower.

Even in midwinter, a difference of almost 7°C. could be measured between the shadowed surface and the sunward side of the metal structure. The gradual expansion resulting from solar heating of the sunward exposure thus produced a measurable bending away from the changing direction of the sun. There was a noticeable time-lag of course. This varying daytime tilt-component thus combined with the average night-time value to produce the observed behavior.

Sharper gradients occur at sunrise and sunset when equilibrium conditions are disturbed. The sudden differential heating at sunrise and the cessation of further heat-input at sunset seem clearly responsible. Some seasonal differences in the night-time averages are also suggested by comparing Figures 2 and 3. The possible influence of cooling winds was not explored, however.

As to general applicability elsewhere, it should be remarked at this point that sharp temperature-gradient effects are <u>not</u> automatically excluded by a radome. Level-sensors mounted on a

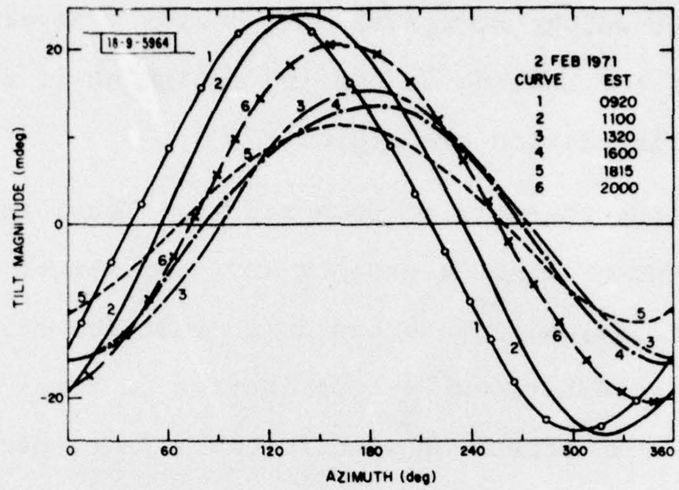

Fig. 2. Level-sensor output during azimuth rotation at various times of day (February 1971).

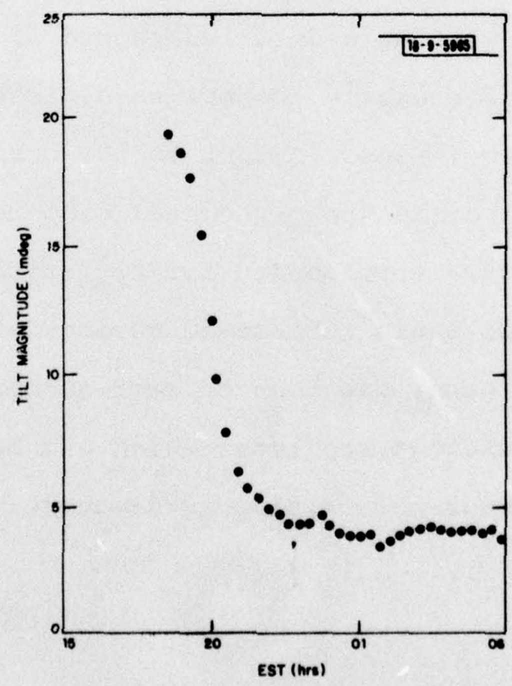

Fig. 3. Variation of pedestal tilt around sunset (June 1972).

protected light-weight structure can provide a novel record of on-off periods for heating or cooling equipment if adequate baffling and circulation are neglected.

At Millstone there is no such radome. Thus, in addition to underlying structural misalignments and temperature-related diurnal variations, Millstone has to correct for still a third -- and sometimes more serious -- contribution to tower tilt. This is the measurable effect of wind forces. Short-period gusts during a live track might leave a recognizeable signature or be noted by an operator for later editing. However, the effects of steady winds vary rather smoothly with antenna aspect-angle. The varying error so introduced into the observations can not be removed subsequently without a detailed record of the tilt history. Such a process is more easily accomplished directly in real-time using calibrated level-sensor output to the computer. Two level-sensors 90° apart provide the orthogonal components of the instantaneous tilt (vector) needed for real-time corrections. Once the level-sensors are calibrated during calm conditions chosen by the user, they can then correct automatically for many of the conditions encountered later which are beyond the user's control. Level-sensor calibration is discussed in Appendix A.

III. PREDICTION ERRORS WITH ANTENNA TILT

A. ORBIT-FITTING ASSUMPTIONS

One measure of the importance of real-time tilt corrections for accurate orbit determination can be derived assuming only a fixed vertical misalignment (tilt magnitude and direction). Such an assumption represents an immense simplification of real life for Millstone, and probably for any exposed antenna subject to temperature variations and winds. By the same token, it also represents the best that can be expected for a protected antenna with uncorrected vertical misalignment. The resulting error estimates should therefore be quite conservative for Millstone but should be widely applicable elsewhere.

A second assumption concerns the type of orbit observed. A typical high-eccentricity Molniya orbit was selected, that belonging to SDC #9829. Millstone's attention is currently reserved primarily for deep-space targets. The results are therefore again particularly relevant for Millstone, but they would also be applicable wherever observations of such a target are limited primarily to a single sensor.

Finally, the procedure by which observations are selected and predictions are made in this study is the same as the one commonly employed at Millstone for building up a file of high-quality observations following an initial track. In this approach, a precision orbit is fitted by least-squares to observations from at least two separate tracks. Strong consistency requirements are thus imposed, as the physical laws of motion act throughout the entire period from the first observation to the last. Such constraints are very much less effective over the relatively brief duration of a single track alone. The prediction errors resulting from fitting an orbit to multiple-pass observations thus tend to be much smaller than those obtained from an equivalent number of closely spaced observations of a single pass alone. The error estimates arising from uncorrected tilt in the observations of the two passes used in the simulations should once again be conservative in comparison with predictions based on observations of one pass alone.

B. SIMULATION TECHNIQUE

Simulated observations were first generated from mean orbital elements for SDC object #9829.* The ground-trace for this object is shown in Figure 4. Two tracking intervals were selected three days apart, a period not unusual for deep-space tasking at Millstone. Current practice there is to take five observations on each routine target. Five simulated observations were selected at one-minute intervals centered around the following points:

*A high-precision numerical integration program was used for all the orbit-fitting and orbit generation used in the study. (See Ref. 4.)

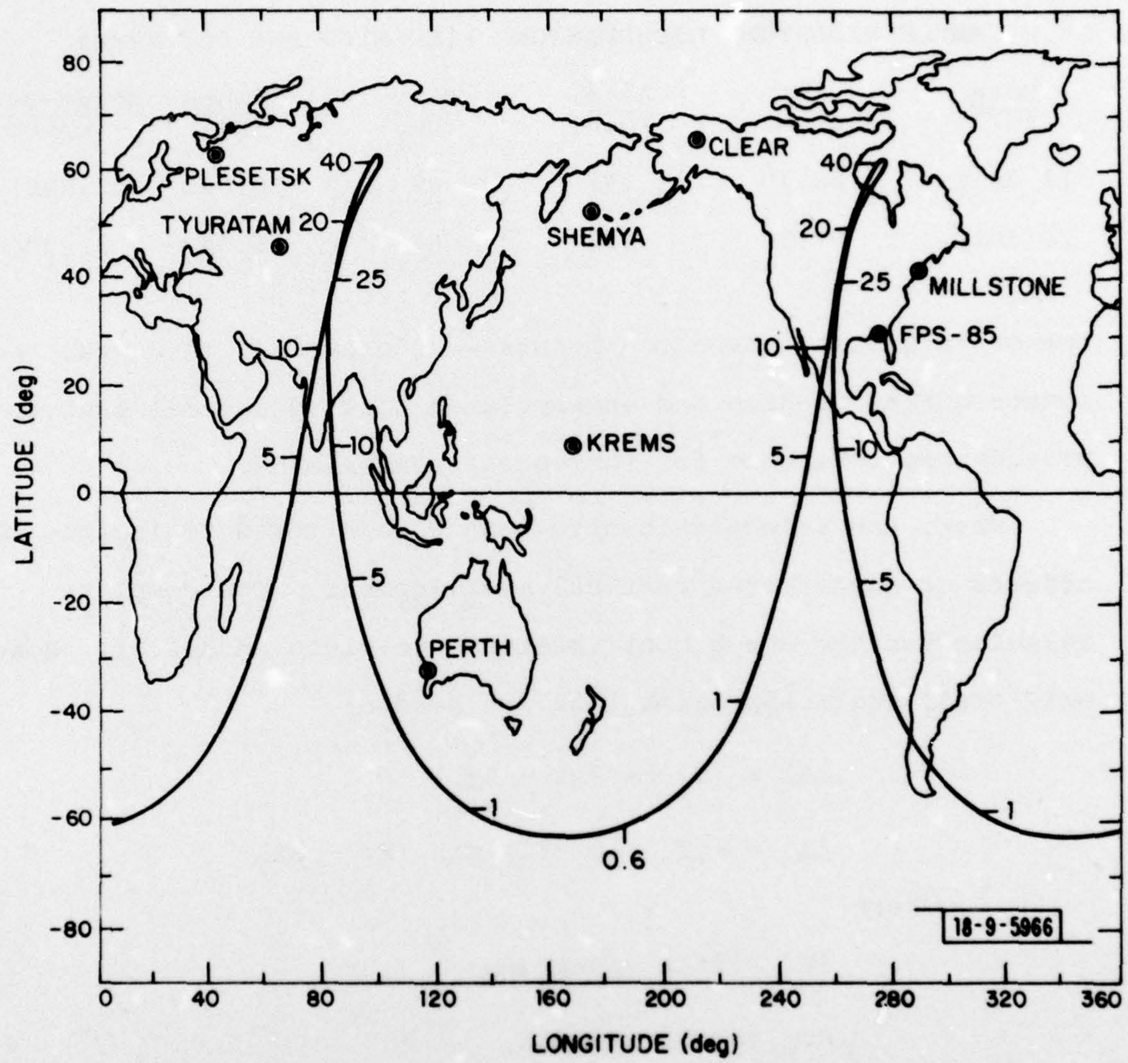

Fig. 4. Object #9829 Ground-trace and altitude (km × 10^3).

TABLE I

SAMPLE MILLSTONE OBSERVATIONS SIMULATED FOR SDC #9829

Date (1977)	GMT (Hr,Min)	Azim (Deg)	Elev (Deg)	Range (Km)	Range-Rate (m/sec)
21 July	08:10	298	67	20,000	2,900
24 July	07:30	272	61	15,000	3,200

The orbit fitting these ten points was determined in a weighted least-squares fashion and extrapolated forward several days to provide the reference for subsequent comparisons.

Next, the selected observations were altered to include the effects of uncorrected vertical misalignment. The complete formulas for the error contributions are given in Ref. 1. However, only small-angle approximations are needed:

$$\Delta El = |T| \cos (Az - Az_T)$$

$$\Delta Az = -|T| \tan (El) \sin (Az - Az_T)$$

where

$|T|$ = Tilt magnitude

Az_T = Tilt azimuth

It is evident from these simplified relations that elevation measurements can be perturbed by the full magnitude $|T|$ of the misalignment at certain azimuths ($Az = Az_T$ and $Az = Az_T + 180^o$). Azimuth is similarly affected at azimuths 90^o removed from the direction of tilt. However, at high elevations the factor tan (El) can dominate, producing an azimuth error larger than the magnitude of the misalignment itself.

Initially, a fixed tilt of 25 mdeg (0.025 deg) was postulated at 120° azimuth, based upon curve 1 shown in Fig. 2. Magnitudes of 50 mdeg and 75 mdeg at the same azimuth were also tried for comparison. Perturbations for the sample points shown in Table I are given in Table II.

TABLE II

POINTING ERRORS WITH 0.025° TILT AT 120° AZIMUTH

Date (1977)	GMT (Hr,Min)	ΔAzimuth (deg)	ΔElevation (deg)
21 July	08:10	-0.002	-0.025
24 July	07:30	-0.021	-0.022

The corresponding errors with 50 mdeg and 75 mdeg tilt at 120° azimuth can be obtained by doubling and tripling (respectively) the values shown in Table II.

It should be noted in passing that the assumed tilt-azimuth is outside the range where the factor tan (El) ~ 2 can produce azimuth errors larger than the misalignment. In this respect, the example chosen is by no means a worst case.

The third step was to fit an orbit to the modified observations in the two tracking intervals. (Further details are given in Appendix B.) This step was repeated with the appropriate modifications for tilt-magnitudes of 50 mdeg and 75 mdeg. Finally, the orbits fitted to the altered observations were compared in turn with the original reference (unperturbed) for the period immediately following the second track. The vector magnitudes of the respective displacements are shown in Fig. 5 as functions of time.

IV. DISCUSSION OF RESULTS

The presence of vertical misalignment and the absence of corresponding corrections leads directly to pointing errors at the times of observation. The vector magnitudes of the resulting errors at those times may be significant in themselves, depending on the magnitude of the misalignment and its azimuth in relation to the target azimuth.

If the previous pointing errors remain fixed, re-acquisition of an object in half-synchronous orbit is not necessarily difficult. The same radar searching the part of the orbit where the target was last seen will have similar offsets. However, the errors in determination of the true orbital parameters can be quite significant, even with relatively small errors in the observations.

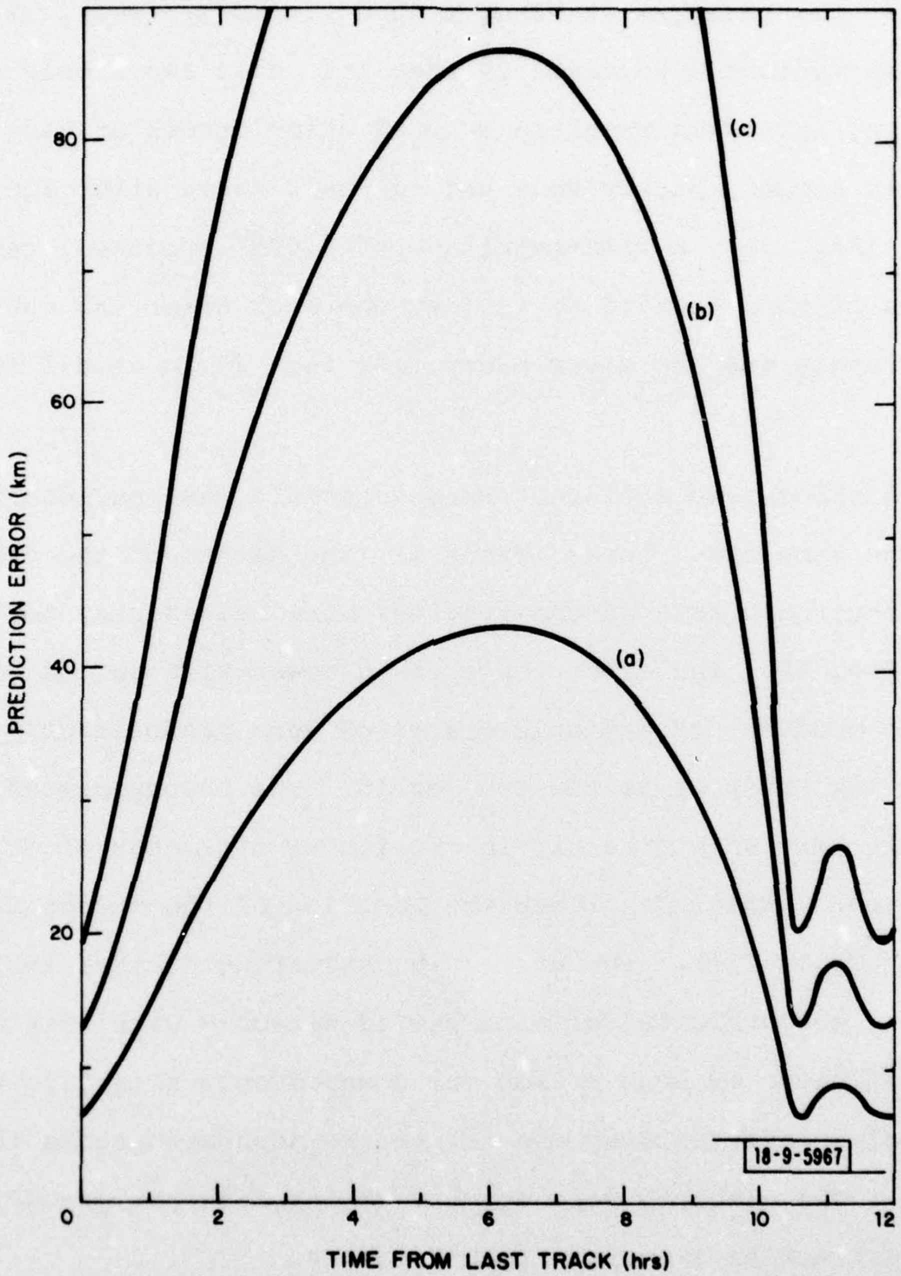

Fig. 5. Vector magnitude of prediction errors with constant uncorrected tilts of (a) 25, (b) 50, (c) 75 mdeg at 120° azimuth during two earlier tracks.

In the examples at hand, a good fit to systematically corrupted observations with fixed 25 mdeg tilt over two widely separated tracking intervals resulted in prediction errors of more than 40 km near apogee, barely four and one-half hours after the second track (Fig. 5). A tilt-magnitude of 0.075° produced prediction errors of more than 40 km in just one hour after the second track. Only rarely was the discrepancy less than 20 km at all for this case.

Although two different range intervals were purposely chosen for the simulated tracks (Table I), the nature of the orbit was such that both sets of observations were necessarily to the West (see Fig. 4). The effect of a fixed tower-tilt to the Southeast was to produce prediction errors which were predominantly out of plane with respect to the true orbit. The uncompensated effects of tilt were seen directly in the faulty estimates of orbital longitude*, which describes the position of the target in its orbit (Table III). The errors in estimating orbital inclination (i) and eccentricity (e) also varied directly with tilt magnitude. The estimates of mean motion (n) changed only slightly, being strongly constrained by the fit to two separate tracks three days apart. The elements were epoched at the midnight preceding the second track as a matter of convenience.

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*The mean orbital longitude is the <u>sum</u> of the three angles: mean anomaly (M), argument of perigee (ω), and right ascension of the ascending node (Ω).

TABLE III

ERRORS IN DETERMINING MEAN ORBITAL ELEMENTS FOR

VARIOUS MAGNITUDES OF UNCORRECTED TILT AT 120° AZIMUTH

Orbital Element	Reference Value	Vertical Misalignment (|T|) 0.025°	0.050°	0.75°
i	62.925°	+0.044	+0.089	+0.133
e	0.73675	-0.0001	-0.0002	-0.0003
Ω	290.248°	+0.046	+0.091	+0.137
ω	281.176°	-0.021	-0.042	-0.063
M	167.305°	+0.001	+0.003	+0.004
n	2.006635 Rev/Day	$\sim$ 0	$\sim$ 0	$\sim$ 0
$\Omega + \omega + M$:		+0.026°	+0.052°	+0.078°

The pattern of variation of the prediction-error with the passage of time was shown in Fig. 5. The pattern repeats every twelve hours without essential change (Fig. 6).* This periodicity is the basis for the earlier comment that the same radar looking at the same portion of the orbit where the target was last tracked might not necessarily have severe reacquisition problems. The element-sets derived would obviously not be useful for reacquisition elsewhere on the orbit by the same radar or by other sensors

*A fixed 15-minute step-size in the computations limited the accuracy of detail at the minima.

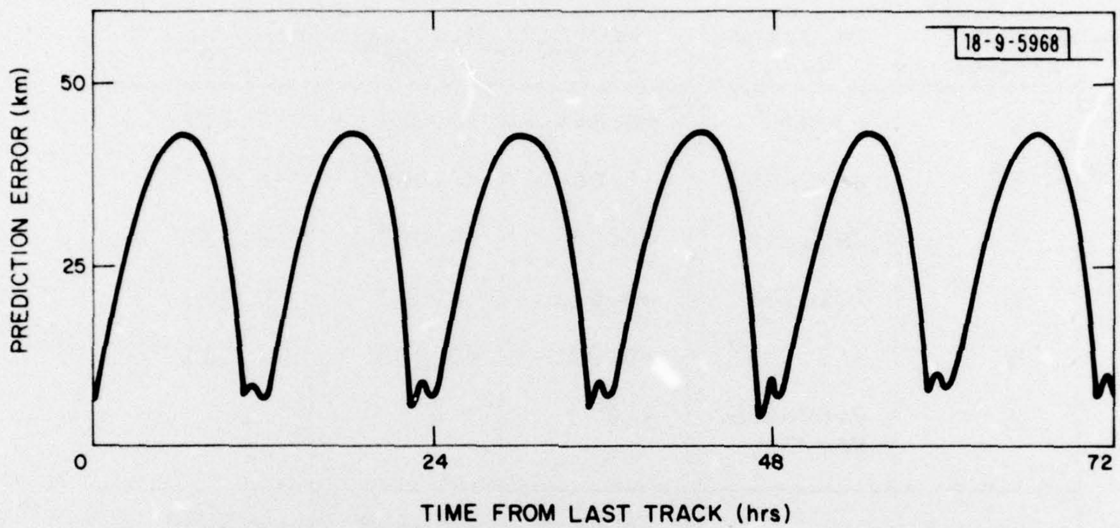

Fig. 6. Vector magnitude of prediction error with uncorrected tilt of 25 mdeg at 120° azimuth during two earlier tracks.

at considerably different locations. For this reason, additional tracks by the same radar would not help the situation much unless different portions of the orbit could be covered.

Somewhat longer tracks in the regions sampled would likely result in larger angle residuals, of course, but these might well go unnoticed in the normal presence of noise. They would not, of themselves, give clear evidence of an underlying tilt problem in the absence of other knowledge.

The problem addressed and illustrated in the numerical examples has been considerably simplified. The basic assumptions discussed in the previous section appear conservative and were drawn from available experience. Nonetheless, the effects of uncorrected vertical misalignment in producing orbit-determination errors appear potentially serious. The more complicated effects of variable misalignments are not likely to be less serious. They will only be harder to correct without direct measurement techniques.

V. SUMMARY

1. Misalignment of an antenna's vertical reference axis with respect to the local vertical has been examined as a source of prediction errors.

2. Numerical examples have been presented to illustrate the potentially serious effects which such misalignment can have on accurate orbit determination for deep-space targets.

3. An essential distinction has been emphasized between orbit-determination as a whole (for handover or other missions) and the simpler problem of target re-acquisition by a single radar which has already made previous observations.

4. The role of antenna-pedestal level-sensors in making real-time corrections for vertical misalignment has been outlined. Calibration procedures developed at the Millstone Hill Radar for this purpose have been described in detail.

APPENDIX A

LEVEL-SENSOR CALIBRATION

A number of commercially available electronic level-sensors make use of a bubble in a spirit level. Movement of the bubble produces a varying imbalance in a capacitance bridge network. An associated electronics package provides the amplification needed. The conversion factor between angular offset and resulting output signal must therefore be determined, and the D. C. bias present in the output must also be known for each sensor in order to make real-time corrections to pointing data in the computer.

A/D hardware will set some limits on the amplification desireable. Stability and linearity considerations favor avoidance of more amplification than needed. Typical values in use at Millstone have ranged from about 200 - 280 arc sec/volt (55 - 78 mdeg/volt).

The method of calibration employed at Millstone is direct. It requires quiet conditions and priority use of the antenna. Each sensor in turn is removed from its mounting bracket beneath the azimuth deck and mounted instead on a "sine bar." A digital voltmeter* is then used to read the output obtained at the A/D converters for a sequence of micrometer-set angular offsets on

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*The computer itself would be a preferred recording device when available.

either side of zero. The whole chain (from sensor to computer) used during actual tracking is thus included in the calibration.

For this purpose, extraneous additions to the quiescent tower tilt must be avoided. The hours midway between sunset and sunrise on wind-free nights give the best results. The antenna dish is kept upright to minimize the cross-sectional area exposed to even mild wind forces, as the measurements may have to be repeated and averaged if tower movement is present.

The voltage differences for the equal but oppositely signed angular offsets around zero (inserted by the "sine bar") are tabulated, and the ratios of voltage difference to symmetric angular-offset difference are then averaged. The reciprocal is the conversion constant (angular units/volt) needed in the computer to correct pointing data in real time.

The "sine bar" measurements typically take several hours. Intervals between calibrations have sometimes gone as long as nine months, and the need for re-calibration has occasionally been evident in as little as one month.

The presence of the two orthogonal level-sensors also provides a handy diagnostic tool. Two independent estimates of tilt magnitude are obtained over each complete revolution of the antenna in azimuth. The calibration factors may differ for the two sensors, but the computed tilt-magnitudes should be similar unless one sensor has changed with respect to the other. The test is incomplete in that both sensor outputs might conceivably drift together. Such occurrences -- if any -- have not been detected.

The same azimuth rotations used for comparison of tilt-magnitude estimates are used for estimating the D.C. bias levels. The sinusoid fitted to each sensor's output over 360° azimuth gives the D.C. bias ("constant") term directly. It is also equivalent to the average of all the sampled values taken over 360°.

Generally, a minimum of six complete rotations (three in each direction) are used at Millstone, and the estimates are then averaged for each sensor. Typically the antenna is driven at a constant rate of one degree per second, values are sampled at fifteen per second, and the dish is pointed upright to preserve aspect-angle symmetry with respect to any winds present. The process takes about forty minutes using the ANTICAL computer software.[1]

APPENDIX B

ORBIT-FITTING DETAILS

In order to establish a reference-orbit as a basis for comparison, two tracking intervals were selected. These consisted of five observations each, one minute apart. The observation intervals themselves were three days apart, and both were at about the same time of day, early morning. (Similar pedestal tilts for an exposed antenna might then be reasonably expected.)

The intervals were also chosen to cover different slant-ranges in order to avoid sampling exactly the same portion of the orbit for both tracks. Thus a number of conservative selection criteria were applied, as discussed earlier, to avoid picking an atypical worst-case. Indeed, an attempt was made to simulate the usual routine deep-space tasking as currently practiced at the Millstone Hill Radar for a target in 12-hour orbit.

Four-coordinate observations were used, based at Millstone as listed in Table B-1.

TABLE B-1

MILLSTONE DATA-BASE USED FOR REFERENCE-ORBIT

Date (1977)	GMT (Hr,Min)	Azimuth (Deg)	Elevation (Deg)	Range (Km)	Range-Rate (m/sec)
21 July	0808	296.190	66.496	19597	2919
	0809	297.091	66.597	19772	2904
	0810	297.978	66.686	19945	2889
	0811	298.853	66.770	20118	2874
	0812	299.715	66.847	20290	2859
24 July	0727	268.789	59.344	14638	3214
	0728	269.866	59.860	14831	3211
	0729	270.944	60.349	15024	3207
	0730	272.025	60.813	15216	3201
	0731	273.106	61.253	15408	3195

An iterative weighted-least-squares process was used to determine the best-fit orbit. The data-weights were defined (inversely) from postulated standard deviations of 0.001 deg in angle, 1 km in range, and 1 m/sec in range-rate specified to the program[4].

The RMS residuals and their means with respect to the fitted orbit were negligible. Of course, the observations had previously been generated from such a trajectory. Some slight adjustments were necessary in the orbit fitted to the selected observations *ab initio* because of their reduced precision. (The number of decimal places retained in the original observations generated was reduced, so the residuals were no longer identically zero.) The orbit fitted to the truncated observations actually used thus provided the proper reference for later comparisons.

The observations were modified in turn to include the effects of pedestal tilt. The error contributions arising from this cause were computed as follows.

TABLE B-2

POINTING ERRORS WITH 0.075° TILT AT 120° AZIMUTH

Date (1977)	GMT (Hr,Min)	Δ Azimuth (Deg)	Δ Elevation (Deg)
21 July	0808	-0.011	-0.075
	0809	-0.009	-0.075
	0810	-0.006	-0.075
	0811	-0.003	-0.075
	0812	-0.001	-0.075
24 July	0727	-0.065	-0.064
	0728	-0.065	-0.065
	0729	-0.064	-0.065
	0730	-0.063	-0.066
	0731	-0.062	-0.067

One-third and two-thirds of these values were used for tilt-magnitudes of 0.025° and 0.050°, respectively

The same orbit-fitting process used previously was then repeated for each of the three sets of perturbed observations.

The residual means obtained in refitting the perturbed observations (with the same data-weighting used throughout) generally remained negligible. However, range-rate was the measurement most sensitive in this respect to the errors introduced. The residual mean rose to 0.4 m/sec for $|T| = 0.025°$. The values for $|T| = 0.050°$ and $|T| = 0.075°$ were 0.8 and 1.2 m/sec, respectively.

The standard deviations obtained are shown below for the various tilt-magnitudes at 120° azimuth.

TABLE B-3

STANDARD DEVIATIONS FOR PERTURBED OBSERVATIONS RELATIVE TO BEST-FIT ORBITS

Tilt Magnitude (Deg)	Range (m)	Azimuth (deg)	Elevation (deg)	Range-Rate (m/sec)
0.025	110	0.0008	0.0004	0.25
0.050	245	0.0015	0.0007	0.36
0.075	360	0.0025	0.0009	0.51

The numbers themselves are not particularly significant. The issue of importance is that the pointing errors introduced are easily accommodated and masked by the orbit-fitting process. With live-track data, the situation would be further confused by the presence of noise.

The sensitivity of range-rate data to the perturbations has already been noted. However, relatively few radars make a direct measurement of Doppler. Even if available, the sensitivity of range-rate measurements to other sources of error would tend to lessen their utility as a diagnostic for systematic, non-constant pointing errors.

REFERENCES

1. J. V. Evans, editor: "Millstone Hill Radar Propagation Study: Calibration," Technical Report 508, Lincoln Laboratory, M.I.T. (5 October 1974), DDC AD-779689/9.

2. "Millstone Hill Observatory," Lincoln Manual 51, Lincoln Laboratory, M.I.T. (4 April 1964).

3. J. C. Ghiloni, editor: "Millstone Hill Radar Propagation Study: Instrumentation," Technical Report 507, Lincoln Laboratory, M.I.T. (20 September 1973), DDC AD-775140.

4. "Functional Specifications of Lincoln Laboratory Orbit Determination Programs," TRW Systems, Redondo Beach, California (10 May 1966), DDC AD-643376.

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17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

orbit determination	real time	orbit fitting
level sensors	antenna tilt	deep-space tasking

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Accidental misalignment of an antenna's vertical reference axis with respect to the local vertical introduces errors into the measurements of azimuth and elevation directly. If corresponding corrections are neglected, relatively small misalignments can prevent a radar from achieving high-accuracy orbit-determination. The use of electronic level-sensors for making such corrections in real-time is described. Some numerical examples are presented to illustrate the problem.

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